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Title: Validation of nonlinear physics in cross-beam energy transfer

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Validation of nonlinear physics in cross-beam energy transfer

LSCI Program Review

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Acknowledgements

- B. J. Albright[1], K. L. Nguyen[1,2], A. Hansen[2], J. P. Palastro[2], D. Froula[2], D. Turnbull[2], R. F. Bird[1], and W. D. Nystrom[1]

  [1] *Los Alamos National Laboratory*

  [2] *University of Rochester, Laboratory for Laser Energetics*

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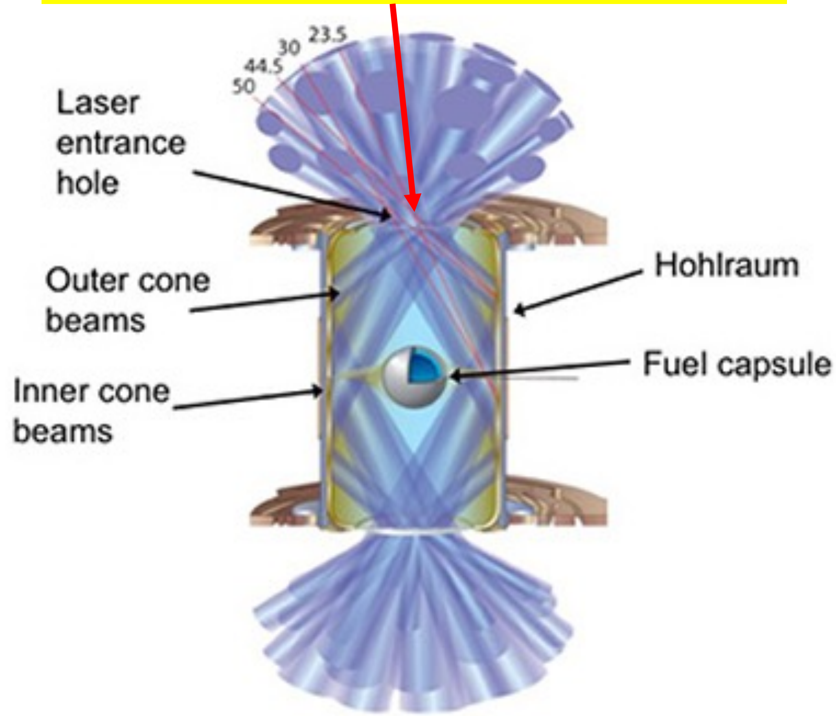
Control of laser-plasma instabilities (LPI) is critical for inertial fusion

- LPI scatter laser light out of the hohlraum and impede the efficient coupling of laser energy to the fuel capsule
- Mitigating LPI requires understanding complex, nonlinear, kinetic plasma behavior
- This requires large-scale simulations on platforms like Trinity KNL
- In this LSCI project, our modeling of the Cross-Beam Energy Transfer (CBET*) LPI process on Trinity led to new insights into the behavior of LPI with high intensity lasers

CBET spoils the the implosion symmetry

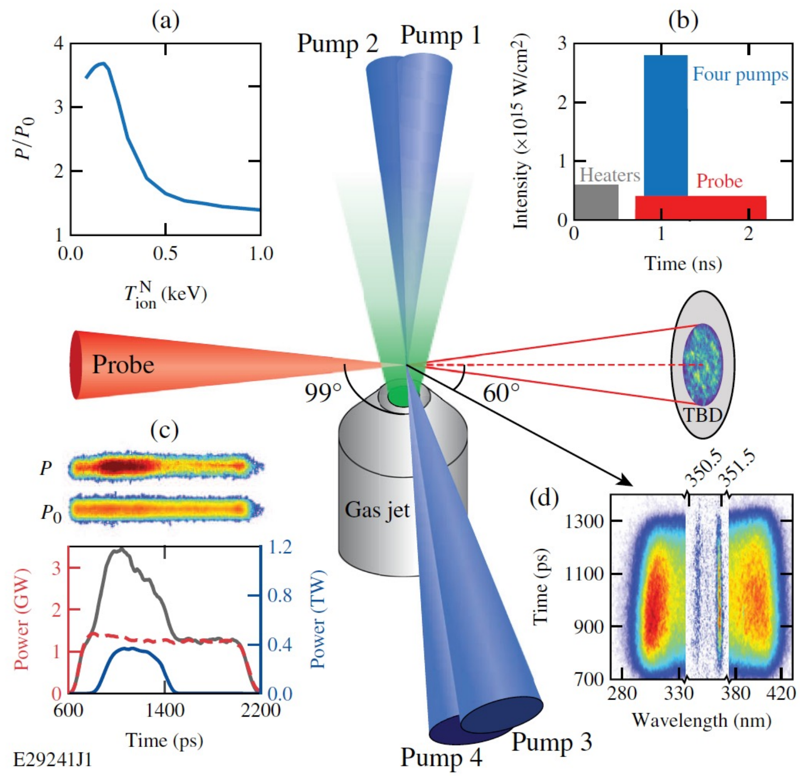


Laser-driven hohlraum on the NIF

*CBET is a process by which energy from overlapping laser beams is transferred between beams through the excitation of ion waves

Our goal was to use LSCI simulations to understand CBET and develop reduced models for codes like xRAGE

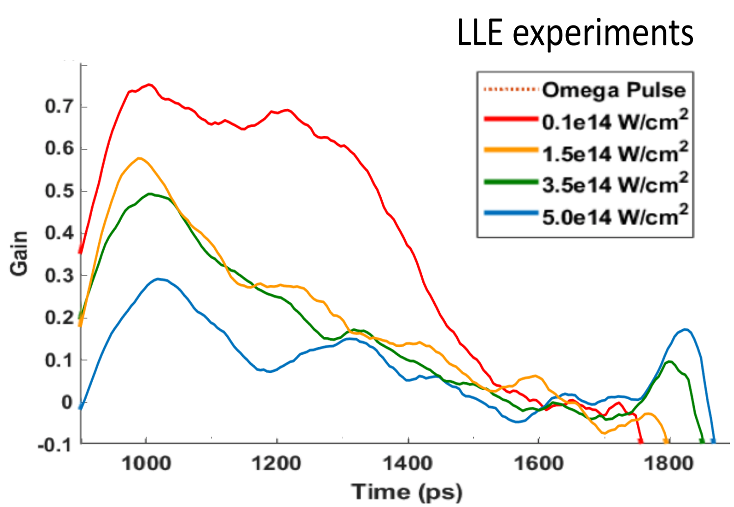
- Inline LPI models in rad-hydro codes are overly simplified and fail to describe fully the experiments
- We sought to identify the governing nonlinear physics of CBET for new LPI physics models in ICF design codes such as xRAGE
- To provide rigorous validation, we worked with colleagues at the Laboratory for Laser Energetics (LLE) to design and model focused experiments[1] using their unique plasma and optical diagnostics

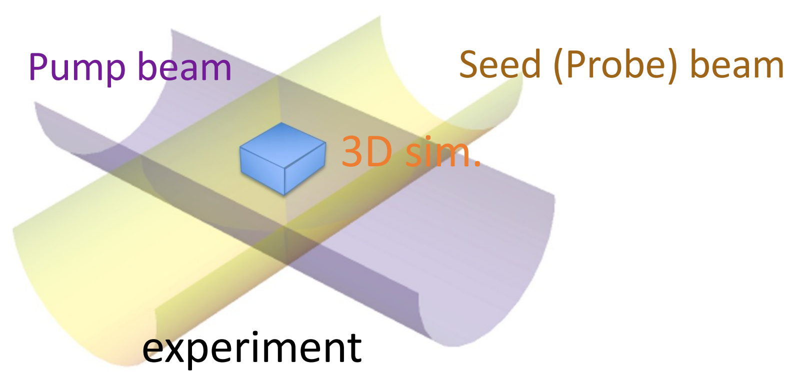


[1] Hansen et al., Phys. Rev. Lett. **126**, 075002 (2021)

We ran and analyzed in detail a series of 2D and 3D VPIC simulations to identify the key nonlinearities associated with CBET saturation

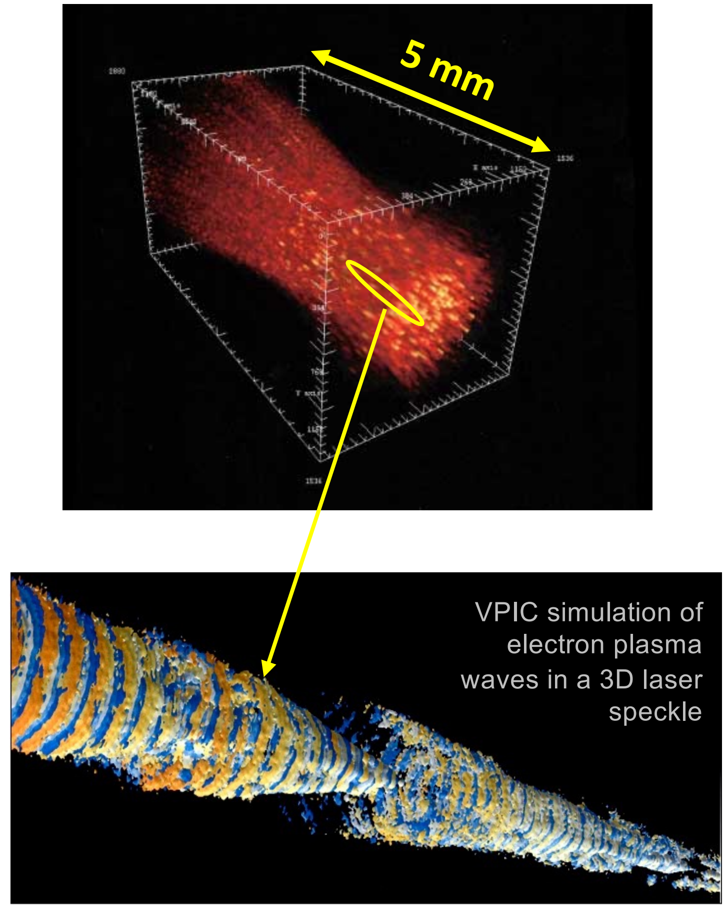
- CBET gain was modeled at a range of intensities and the roles of different physics processes were examined
  - ion trapping in the ion acoustic waves (IAW)
  - collisional de-trapping & heating
  - detuning of resonances because of evolving plasma conditions





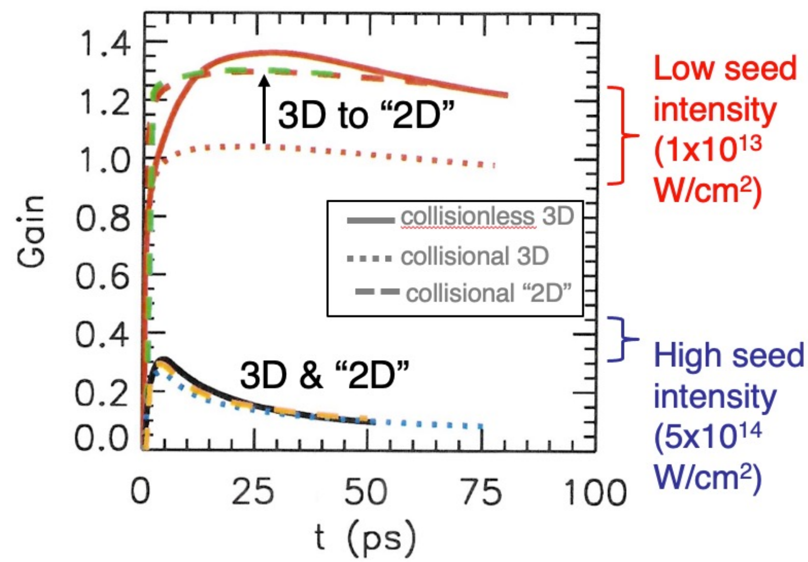
VPIC ran well on Trinity with large simulations using 30% of the KNL partition

- Our study used the VPIC[1] open source plasma kinetic code maintained in the LANL ASC program to model ICF plasma media from first principles
  https://github.com/losalamos/vpic
- VPIC has been optimized to run very efficiently (>10% theoretical peak single-precision floating point efficiency) on Trinity KNL
- VPIC weak scaling is nearly ideal; we were limited by the physics needs of the problem, not the platform
- We did not encounter any serious problems, just occasional file system hiccups or node failures (we benefited from the experience gained in 3 prior LSCI studies)

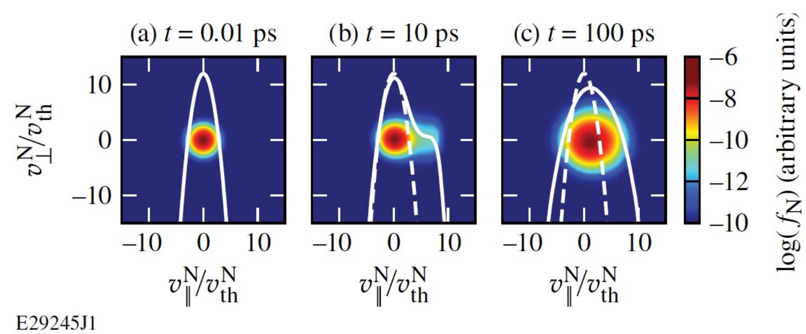


We were able to complete our LSCI study and found that LSCI simulations enabled the understanding of CBET nonlinear saturation

- We were able to complete our LSCI study of CBET
- We found that CBET saturation at high laser seed intensity involves
  - ion trapping
  - detuning of initial resonance from ion collisional heating
- Simulated amount & time scale of ion heating is consistent with experiments[1]
- **The study indicates the feasibility of crafting reduced inline models of CBET saturation physics to improve predictive modeling of ICF**



Pump intensity: 2.2×10^{15} W/cm^2



[1] Hansen et al., Phys. Rev. Lett. **126**, 075002 (2021)

Future work

Our ultimate goal is to implement nonlinear LPI models in design codes like xRage

- We are interested in using LSCI in future studies to model other well diagnosed LPI experiments
- LPI parameter space is large – our goal is to understand nonlinear LPI behavior over a range of settings applicable to ICF and HED experiments
- Our next step is to use what we've learned to build a reduced models of nonlinear CBET that can be implemented into design codes like xRage